본 수업의 주 교재는 Silberschatz, Galvin, Gagne, "Operating System Concepts Essentials 2nd ed.", Wiley, 또는 한글번역본인 박민규, 조유근, "Operating System Concepts 에센셜 2판", 홍릉과학출판사입니다. 본 강의 동영상의 슬라이드는 이 책의 홈페이지에서 제공하는 것을 사용했음을 밝힙니다 (https://codex.cs.yale.edu/avi/os-book/OSE2/slide-dir/index.html). 다만 강의의 편의를 위해 내용 변경 없이 슬라이드 레이아웃을 변경하였고, 진도 관리에 필요한 경우 일부 슬라이드는 생략하였습니다.

Chapter 4: Threads

=> 또다른 실행의 단위

Notion of thread

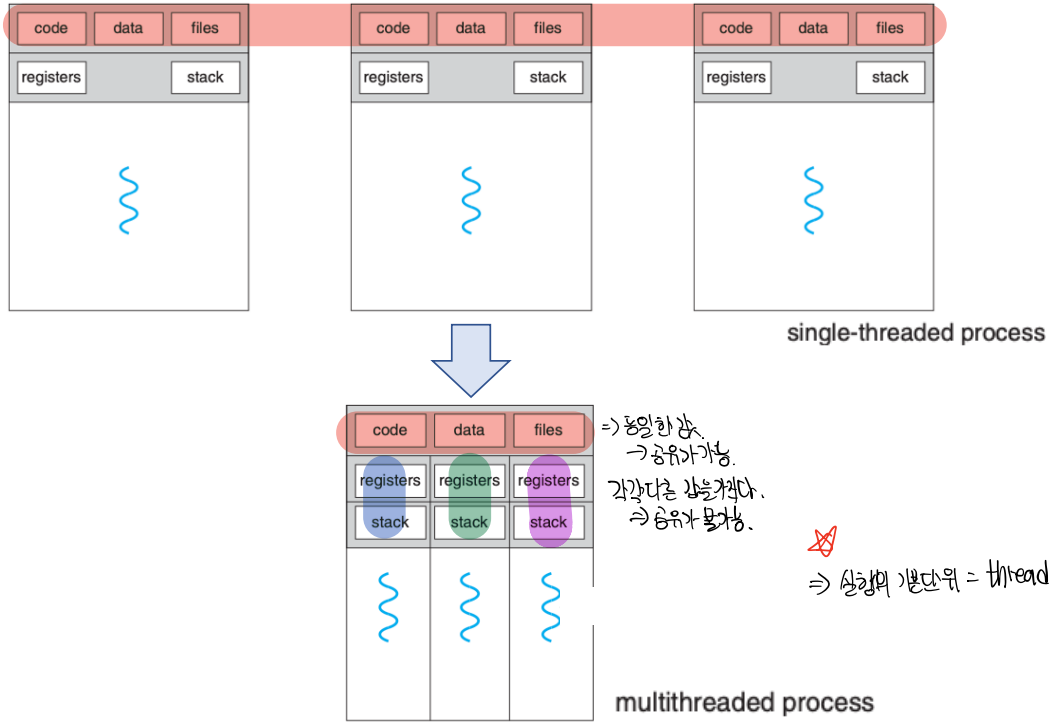
APIs for the Pthread, Windows, and Java thread libraries

Issues related to multithreaded programming

Contents

- Overview
- Multicore Programming
- Multithreading Models
- Thread Libraries pthread, window thread, java thread.
- Implicit Threading 사용자가 직접생성.
- Threading Issues

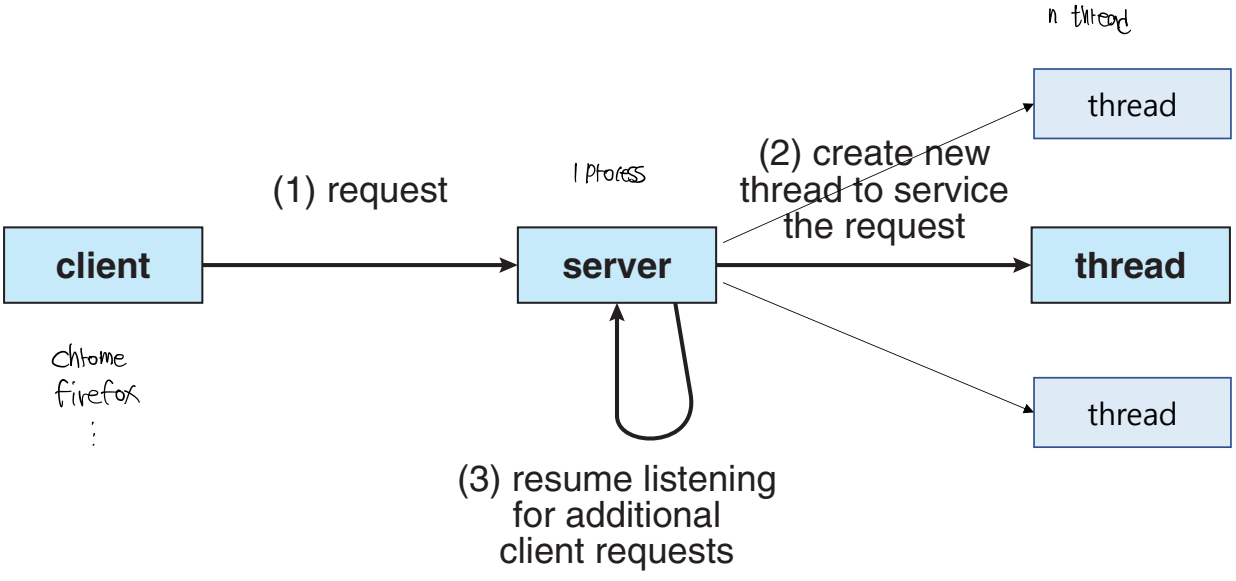
4.1 Overview


code
data
files
registers
stack
single-threaded process
multithreaded process
=> 동일한 code, data, files 공유 가능.
=> 각각 다른 registers, stack 가짐.
=> 실행의 기본단위 = thread.

Motivation

- Most modern applications are multithreaded
- Threads run within application
- Multiple tasks with the application can be implemented by separate threads
  - Update display
  - Fetch data
  - Spell checking
  - Answer a network request
- Process creation is heavy-weight while thread creation is light-weight
- Can simplify code, increase efficiency
- Kernels are generally multithreaded

Multithreaded Server Architecture

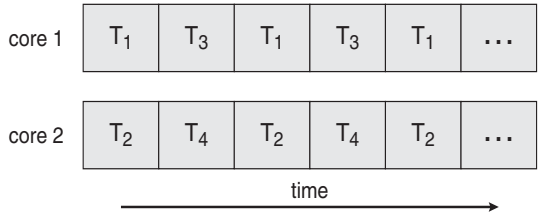


Benefits

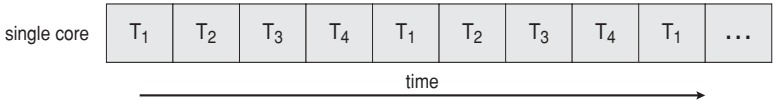
- **Responsiveness –** may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources of process, easier than shared memory or message passing 자원쉽게공유가능.
- **Economy –** cheaper than process creation, thread switching lower overhead than context switching
- **Scalability –** process can take advantage of multiprocessor architectures

4.2 Multicore Programming

- **Multicore** or **multiprocessor** systems
- ***Parallelism*** implies a system can perform more than one task simultaneously
- ***Concurrency*** supports more than one task making progress
  - Single processor / core, scheduler providing concurrency



Parallelism on a multi-core system



Concurrent execution on single-core system

Multicore Programming (Cont.)

- Types of parallelism
  - **Data parallelism** – distributes subsets of the same data across multiple cores, same operation on each
  - **Task parallelism** – distributing threads across cores, each thread performing unique operation
- **Multicore** or **multiprocessor** systems putting pressure on programmers, challenges include:
  - **Dividing activities**
  - **Balance**
  - **Data splitting**
  - **Data dependency**
  - **Testing and debugging**

Amdahl's Law

⇒ 병렬 실행에 성능향상의 법칙

- Identifies performance gains from adding additional cores to an application th at has both serial and parallel components
- S is serial portion and N processing cores

$$speedup \leq \frac{1}{S + \frac{(1-S)}{N}}$$

- That is, if application is 75% parallel / 25% serial, moving from 1 to 2 cores res ults in speedup of 1.6 times
- As N approaches infinity, speedup approaches 1 / S
- Serial portion of an application has disproportionate effect on performance g ained by adding additional cores

- But does the law take into account contemporary multicore systems?

4.3 Multithreading models

- **User threads** - management done by user-level threads library =사용자 수준에서 동작
- Three primary thread libraries: 로 사용.
  POSIX **Pthreads** / Windows thread / Java threads
- **Kernel threads** - Supported by the Kernel kernel 수준에서 동작.
- Virtually all general purpose operating systems, including: Windows, Linux, Mac OS X, and Solaris

⇒ 둘 간에 연관관계가 있다.

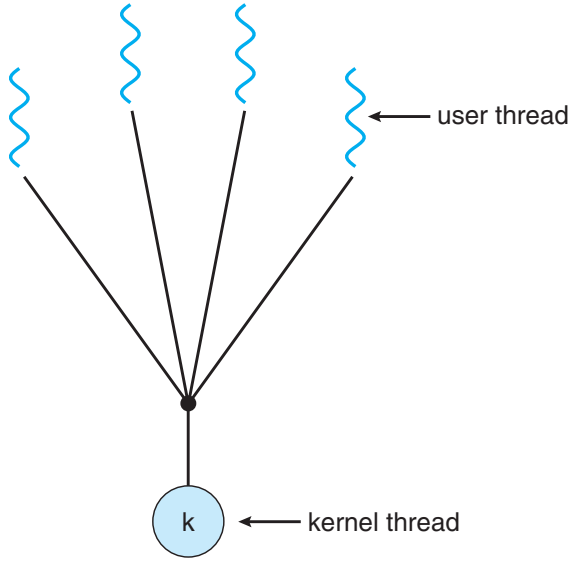
- Multithreading models

  user-kernel의 연관관계 모델.

  - Many-to-One
  - One-to-One
  - Many-to-Many

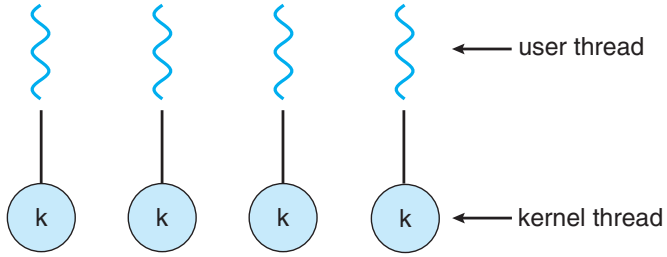
Many-to-One

- Many user-level threads mapped to single kernel thread
- One thread blocking causes all to block
- Multiple threads may not run in parallel on multicore system because only one may be in kernel at a time
- Few systems currently use this model
- Examples:
  - **Solaris Green Threads**
  - **GNU Portable Threads**



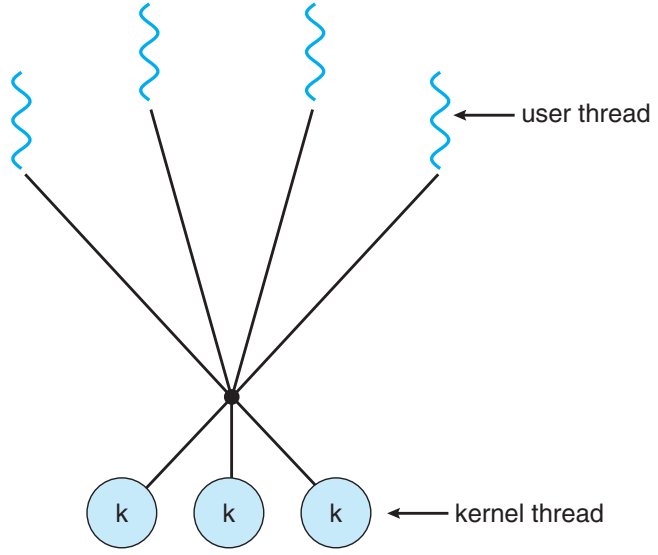
One-to-One

- Each user-level thread maps to kernel thread
- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- Number of threads per process sometimes restricted due to overhead thread의 개수를 제한한다.
- Examples
  - Windows
  - Linux
  - Solaris 9 and later



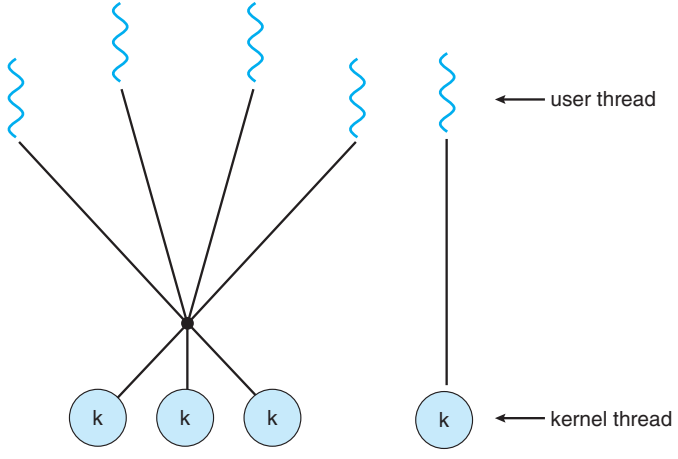
Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads ⇒ multiflexing
- Allows the operating system to create a sufficient number of kernel threads 1 to 1 의단점을 보완이다.
- Solaris prior to version 9 / Windows with the *ThreadFiber* package



Two-level Model

- Similar to M:M, except that it allows a user thread to be **b ound** to kernel thread
- Examples
  - IRIX
  - HP-UX
  - Tru64 UNIX
  - Solaris 8 and earlier



4.4 Thread Libraries

- **Thread library** provides programmer with API for creating and managing threads
- Two primary ways of implementing
  - Library entirely in user space
  - Kernel-level library supported by the OS 과거의 방식
- POSIX Pthreads / Windows Threads / Java Thread

Pthreads

- May be provided either as user-level or kernel-level
- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
- ***Specification***, not ***implementation.*** API specifies behavior of the thread library, implementation is up to development of the library
- Common in UNIX operating systems (Solaris, Linux, Mac OS X)

Pthreads Example

```c
#include <pthread.h>
#include <stdio.h>

int sum; /* this data is shared by the thread(s) */
void *runner(void *param); /* threads call this function */

int main(int argc, char *argv[])
{
   pthread_t tid; /* the thread identifier */
   pthread_attr_t attr; /* set of thread attributes */

   if (argc != 2) {
      fprintf(stderr,"usage: a.out <integer value>\n");
      return -1;
   }
   if (atoi(argv[1]) < 0) {
      fprintf(stderr,"%d must be >= 0\n",atoi(argv[1]));
      return -1;
   }
   /* get the default attributes */
   pthread_attr_init(&attr);
   /* create the thread */
   pthread_create(&tid,&attr,runner,argv[1]);
   /* wait for the thread to exit */
   pthread_join(tid,NULL);

   printf("sum = %d\n",sum);
}

/* The thread will begin control in this function */
void *runner(void *param)
{
   int i, upper = atoi(param);
   sum = 0;

   for (i = 1; i <= upper; i++)
      sum += i;

   pthread_exit(0);
}
```

Windows Multithreaded C Program

```
#include <windows.h>
#include <stdio.h>
DWORD Sum; /* data is shared by the thread(s) */

/* the thread runs in this separate function */
DWORD WINAPI Summation(LPVOID Param)
{
   DWORD Upper = *(DWORD*)Param;
   for (DWORD i = 0; i <= Upper; i++)
      Sum += i;
   return 0;
}

int main(int argc, char *argv[])
{
   DWORD ThreadId;
   HANDLE ThreadHandle;
   int Param;

   if (argc != 2) {
      fprintf(stderr,"An integer parameter is required\n");
      return -1;
   }
   Param = atoi(argv[1]);
   if (Param < 0) {
      fprintf(stderr,"An integer >= 0 is required\n");
      return -1;
   }
```

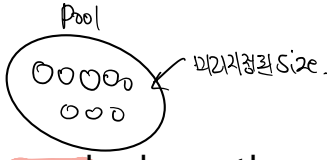
```
   /* create the thread */
   ThreadHandle = CreateThread(
      NULL, /* default security attributes */
      0, /* default stack size */
      Summation, /* thread function */
      &Param, /* parameter to thread function */
      0, /* default creation flags */
      &ThreadId); /* returns the thread identifier */

   if (ThreadHandle != NULL) {
      /* now wait for the thread to finish */
      WaitForSingleObject(ThreadHandle,INFINITE);

      /* close the thread handle */
      CloseHandle(ThreadHandle);

      printf("sum = %d\n",Sum);
   }
}
```

4.5 Implicit Threading

- Growing in popularity as numbers of threads increase, program correctness more difficult with explicit threads
- Creation and management of threads done by compilers and run-time libraries rather than programmers
- Three methods explored
  - Thread Pools
  - OpenMP
  - Grand Central Dispatch

여러방법이있다.

Thread Pools



- Create a number of threads in a pool where they await work
- Advantages:
  - Usually slightly faster to service a request with an existing thread than create a new thread
  - Allows the number of threads in the application(s) to be bound to the size of the pool
  - Separating task to be performed from mechanics of creating task allows different strategies for running task
    - i.e.Tasks could be scheduled to run periodically
- Windows API supports thread pools:

```
DWORD WINAPI PoolFunction(AVOID Param) {
    /*
    * this function runs as a separate thread.
    */
}
```

OpenMP

- Set of compiler directives and an API for C, C++, FORTRAN
- Provides support for parallel programming in share d-memory environments. dentifies **parallel regions** – blocks of code that can run in parallel

- Create as many threads as there are cores

```
#pragma omp parallel
```

- Run for loop in parallel

```
#pragma omp parallel for for(i=0;i<N;i++
  ) {
    c[i] = a[i] + b[i];
}
```

```
#include <omp.h>
#include <stdio.h>

int main(int argc, char *argv[])
{
  /* sequential code */

  #pragma omp parallel
  {
    printf("I am a parallel region.");
  }

  /* sequential code */

  return 0;
}
```

Grand Central Dispatch

- Apple technology for Mac OS X and iOS operating systems. Extensions to C, C++ languages, API, and run-time library 을 확장
- Block is in "^{ }" - `^{ printf("I am a block"); }` Block으로 지정.
- Blocks placed in dispatch queue
  - Assigned to available thread in thread pool when removed from queue

- Allows identification of parallel sections
- Manages most of the details of threading
  => 프로그래머는 병렬실행하고자하는 부분을 표시.

Grand Central Dispatch

- Two types of dispatch queues:
  - serial – blocks removed in FIFO order, queue is per process , called **main queue**
    - Programmers can create additional serial queues within program
  - concurrent – removed in FIFO order but several may be removed at a time
    - Three system wide queues with priorities low, default, high

```
dispatch_queue_t queue = dispatch_get_global_queue
   (DISPATCH_QUEUE_PRIORITY_DEFAULT, 0);

dispatch_async(queue, ^{ printf("I am a block."); });
```

Threading Issues

- Semantics of **fork()** and **exec()** system calls
- Signal handling
  - Synchronous and asynchronous
- Thread cancellation of target thread
  - Asynchronous or deferred
- Thread-local storage
- Scheduler Activations